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RESEARCH MEMORANDUM

PRELIMINARY FLIGHT INVESTIGATION OF THE WING-DROPPING TENDENCY AND LATERAL-CONTROL CHARACTERISTICS OF A 35° SWEPT-WING AIRPLANE AT TRANSONIC MACH NUMBERS

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SUMMARY

Results are presented from a preliminary flight investigation on a swept-wing airplane of the lateral-control characteristics and wing-dropping tendency encountered at high Mach numbers. Measurements of the aileron and rudder-control effectiveness are presented and used with estimated damping-in-roll characteristics and data from steady sideslips to approximate the variation of effective dihedral with Mach number.

The wing-dropping tendency was found to result from a combination of three factors: a small initial directional asymmetry, an abrupt increase in positive dihedral effect, and a reduction in lateral-control effectiveness. Results of the tests suggest that the increase in dihedral effect is due to a separation of flow on the trailing wing in sideslips at high Mach numbers.

INTRODUCTION

Apparent abrupt changes in lateral trim or wing-dropping tendencies have been noted on several airplanes, both straight and swept wing, at high subsonic Mach numbers. Although few quantitative data are available for reference, the "roll-off" has been characterized by pilots as erratic, changing in severity with rate of increase in Mach number, and changing in direction of roll between individual airplanes of the same type. A similar tendency has been observed during exploratory flights conducted by the NACA on a swept-wing fighter airplane at speeds up to 1.05 Mach number and an average altitude of 35,000 feet.

This report presents preliminary information documenting the wing-dropping tendency on the test airplane and illustrating the changes in lateral and directional stability and control characteristics contributing to the problem. To make the information available as rapidly as possible, it is presented with a minimum of analysis.

SYMBOLS

b wing span, feet

C_{l_β} rate of change of rolling-moment coefficient with sideslip angle $\left(\frac{\partial C_l}{\partial \beta}\right)$, per radian

C_{l_p} rolling-moment coefficient due to rolling $\left[\partial C_l / \partial \left(\frac{pb}{2V}\right)\right]$, per radian

p angular velocity in roll, radians per second

q angular velocity in pitch, radians per second

r angular velocity in yaw, radians per second

V true airspeed, feet per second

β sideslip angle, degrees

δ_{a_L} left aileron angle, degrees

δ_{a_R} right aileron angle, degrees

δ_{a_T} total aileron angle $(\delta_{a_L} + \delta_{a_R})$, degrees ("Right" indicates right aileron up.)

δ_r rudder angle, degrees

EQUIPMENT

The tests were conducted on a North American F-86A-5 airplane. The only exterior modifications to the airplane were the four booms shown in the photograph (fig. 1). Figure 2 is a drawing of the airplane which shows the nose-boom airspeed system used to determine true Mach number and pressure altitude. This system was calibrated up to 1.05 Mach number using the NACA radar-phototheodolite method.

The average weight of the airplane during the test runs was 12,750 pounds. Dimensions pertinent to this report are presented in table I.

Standard NACA optical recording instruments supplemented by a 36-channel oscillograph were used to record the test data, which were synchronized at 1/10-second intervals by a timer.

RESULTS AND DISCUSSION

The wing-heaviness or wing-dropping tendency on the test airplane is documented in figure 3 in terms of the aileron control force and position required to hold the wings level in 1g flight at 35,000 feet. The changes in total aileron angle required with increasing Mach number indicate that left-wing heaviness begins at about 0.90 Mach number, reaches a maximum at a Mach number of 0.95, and decreases at higher speeds until lateral balance is restored at 1.05 Mach number. The reversal in aileron control force at a Mach number of 1.00 apparently is due to a hinge-moment characteristic rather than to a reversal in the direction of the rolling tendency. The individual aileron angles and the floating tendency are also shown in figure 3.

The data presented in figure 3 were selected from steady runs at Mach numbers stabilized as much as practicable and, therefore, represent nearly steady-state conditions. In normal flight maneuvers where both Mach number and acceleration were changing, the wing heaviness was actually apparent as an abrupt roll-off which varied in intensity from mild and erratic to quite severe and occurred at Mach numbers anywhere in the range from 0.92 to 0.96. The supersonic Mach number at which normal lateral balance was restored varied similarly. A typical illustration is provided by the records of total aileron angle and rolling velocity on the time history shown in figure 4 of a nominally wings-level dive from 0.80 to 1.05 Mach number. The variations in sideslip angle and rolling and yawing velocities indicate the difficulty of maintaining directionally steady, wings-level flight.

During the measurements just discussed the pilot reported an effect of sideslip or yawing velocity on the wing-dropping tendency. The variation of the lateral-trim characteristics with Mach number in both left and right sideslips, as well as the wings-level condition, is presented in figure 5. These data show that the direction of the wing-dropping tendency, as indicated by the total aileron required to counteract it, is a function of sideslip angle, left sideslip producing a rolling tendency to the right, and right sideslip a rolling tendency to the left. The direction of rolling tendency with ailerons neutral is consistent, assuming positive dihedral, with the small amount of directional asymmetry ($1/4^\circ$ to $1/2^\circ$ right sideslip) shown in figure 5 to be present in wings-level flight. The fact that this directional asymmetry remains substantially constant with Mach number indicates that the increased aileron required for balance at high speeds (fig. 3) is the result of either reduced aileron effectiveness or increased dihedral effect, or some combination of both, at the higher Mach numbers.

The effect of Mach number on the aileron effectiveness $\partial(pb/2V)/\partial\delta_{a_T}$ is shown in figure 6. The rudder effectiveness $\partial\beta/\partial\delta_r$ averaged over a rudder angle of $\pm 14^\circ$ is also presented. Both control surfaces lose effectiveness above 0.87 Mach number and have reduced effectiveness in the range where the wing dropping is serious. In the Mach number range from 0.92 to 1.04, the aileron effectiveness data are shown in a shaded band to indicate a spread in the test results. The data in figure 6 also show an apparent recovery of aileron effectiveness at supersonic speeds although the effect is somewhat masked by the spread in the test results.

Evaluation of the variation in effective dihedral $\partial C_l/\partial\beta$ with Mach number was made in accordance with reference 1 as follows:

$$\frac{\partial C_l}{\partial\beta} = \left[\frac{\partial(pb/2V)}{\partial\delta_{a_T}}\right]\left[\frac{\partial C_l}{\partial(pb/2V)}\right]\left(\frac{\partial\delta_{a_T}}{\partial\beta}\right)$$

The aileron effectiveness term was obtained from figure 6. The damping-in-roll term was obtained from North American Aviation, Inc., estimates to 0.875 Mach number based on the methods of references 2 and 3. These estimates were extrapolated to 1.05, using unpublished results from rocket-powered-model tests of a similar wing plan form as a guide. The final term $\partial\delta_{a_T}/\partial\beta$ was approximated by incremental values $\Delta\delta_{a_T}/\Delta\beta$ obtained from data of the type shown in figure 5. The variation with Mach number of each term at level-flight lift coefficients, as well as the resultant effective dihedral $-C_{l_\beta}$, is presented in figure 7. These data show a very abrupt, approximately fourfold increase in the effective dihedral starting at 0.92 Mach number. Thus, of the total increase of 11.9° aileron angle required to maintain wings-level flight in going from 0.92 to 0.95 Mach number (fig. 3), 7.8° or approximately 65 percent is due to the increase in dihedral effect and 4.1° or 35 percent is attributable to the decrease in aileron-control effectiveness.

It is emphasized that this derivation of dihedral effect is a linear analysis and in the transonic speed range is subject to error due to nonlinear variations in control effectiveness or out-of-trim rolling moment. Thus, the actual variations of rolling moment with sideslip angle may be variable or even discontinuous and be affected considerably by airplane lift coefficient, particularly if the changes are due to separation effects as suggested in a following paragraph. The preceding quantitative data apply to conditions at the maximum sideslip angle obtainable at level-flight lift coefficients with 300 pounds rudder pedal force. The investigation will be extended to intermediate sideslip angles and higher lift coefficients on a second F-86A airplane equipped to measure wing pressure distribution.

Some additional observations made during the test flights are felt to be significant with regard to the wing-dropping tendency. As has been mentioned briefly in connection with figure 4, test runs made at very small sideslip angles in both directions in maneuvers where the Mach number and normal acceleration were changing resulted in erratic changes in the roll-off characteristics. These effects were of a nature to suggest that the changes in rolling moment or dihedral effect are due to separation of flow over the trailing wing in sideslips at high Mach numbers This behavior is similar to what has been observed at low speeds and high lift coefficients on low wing airplanes, as in the case reported in reference 4.

In view of the effect of the directional asymmetry noted in figure 5, it is also of interest that it was found to be possible to penetrate the roll-off regime without using excessive aileron control, as shown by the point at 0.95 Mach number in figure 5, by flying at exactly the correct sideslip angle. In this condition, the airplane was very unsteady and less than half a degree change in sideslip resulted in a roll-off, suggesting that under practical flying conditions elimination of the directional asymmetry would not necessarily eliminate the roll-off but might reduce its severity.

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4. Lockwood, Vernard E., and Watson, James M.: Stability and Control Characteristics at Low Speed of an Airplane Model Having a 38.7° Swept-Back Wing with Aspect Ratio 4.51, Taper Ratio 0.54, and Conventional Tail Surfaces. NACA TN 1742, 1948.

TABLE I.– DIMENSIONS OF TEST AIRPLANE

Wing	
Area	287.9 sq ft
Span	37.1 ft
Aspect ratio	4.79
Taper ratio	0.51
Dihedral	3°
Sweepback of 0.25–chord line	$35^\circ14'$
Aerodynamic and geometric twist (washout)	2°
Ailerons	
Area, each	18.6 sq ft
Span	9.18 ft
Chord, average	2.03 ft
Deflection, maximum	14° up, 14° down
Boost	hydraulic
Aerodynamic balance	curtain–sealed, paddle balance
Inboard end at	51.6% b/2
Vertical tail	
Area, total	34.4 sq ft
Span	7.5 ft
Aspect ratio	1.74
Taper ratio	0.36
Sweepback of 0.25–chord line	$35^\circ00'$
Rudder	
Area	8.1 sq ft
Span	6.6 ft
Chord, average	1.23 ft
Deflection, maximum	24.8° right, 25° left

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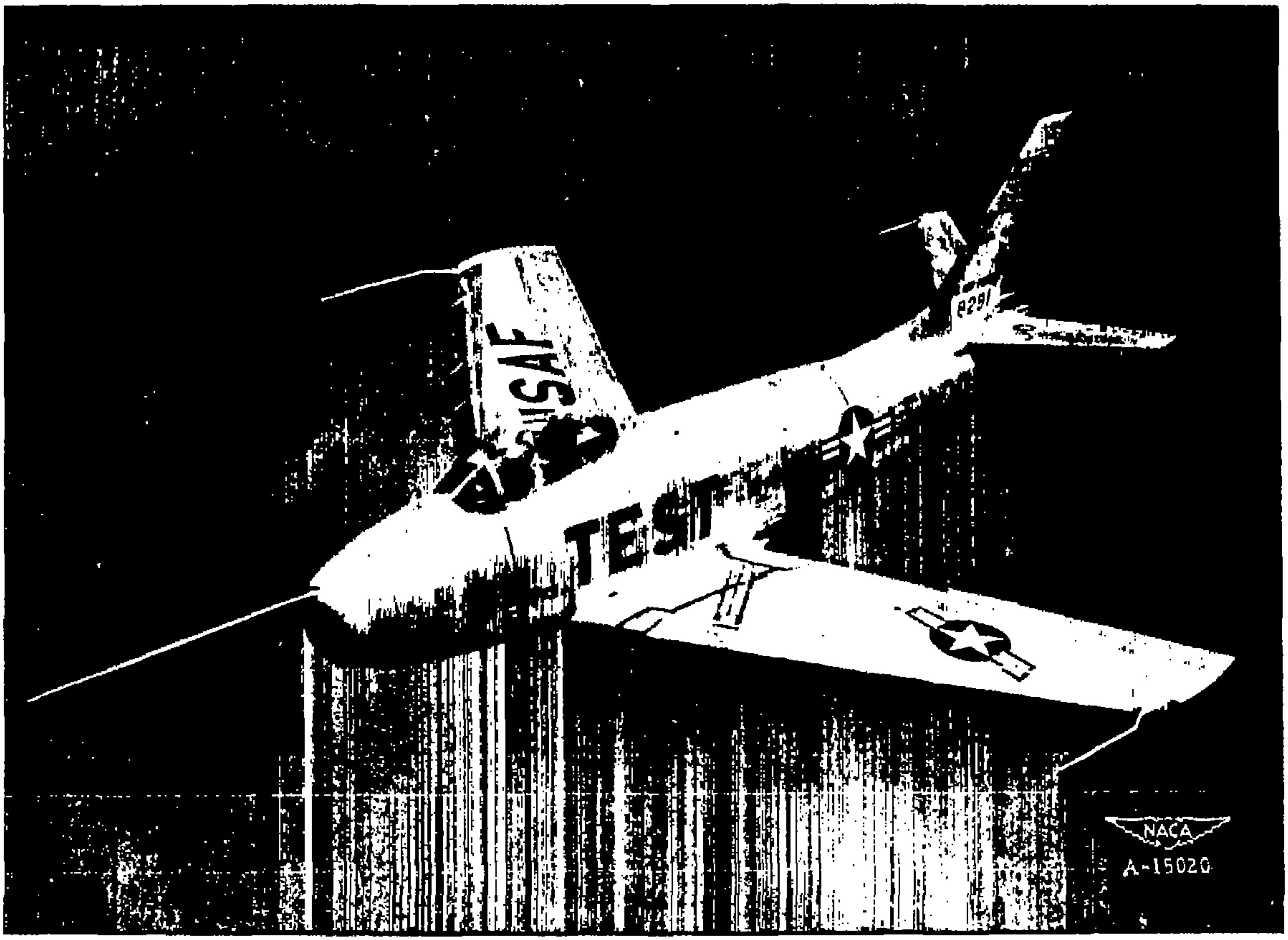

Figure 1.- Photograph of the test airplane showing the wing-tip and nose-boom installations.

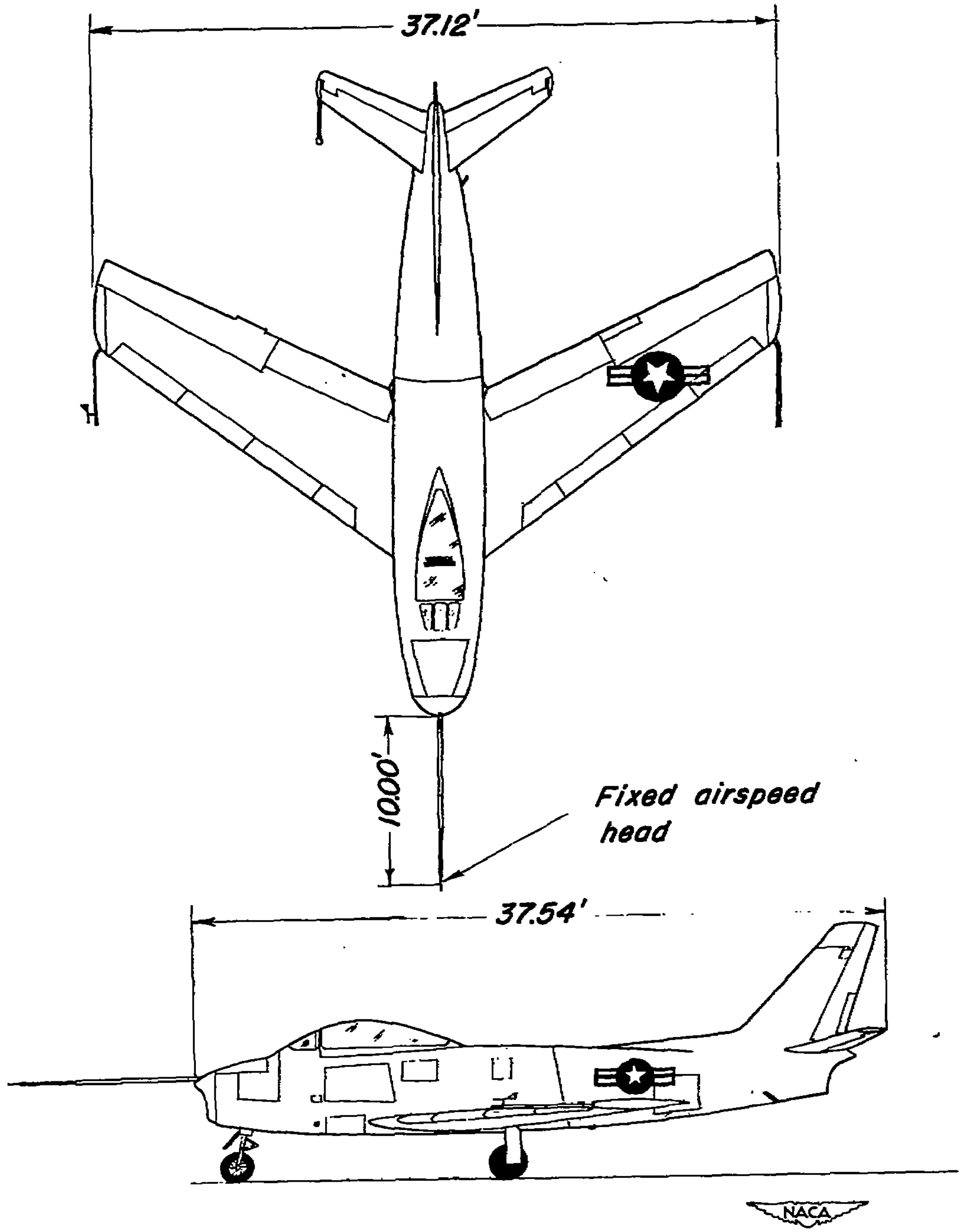

Figure 2.-Two-view drawing of test airplane showing research airspeed installation.

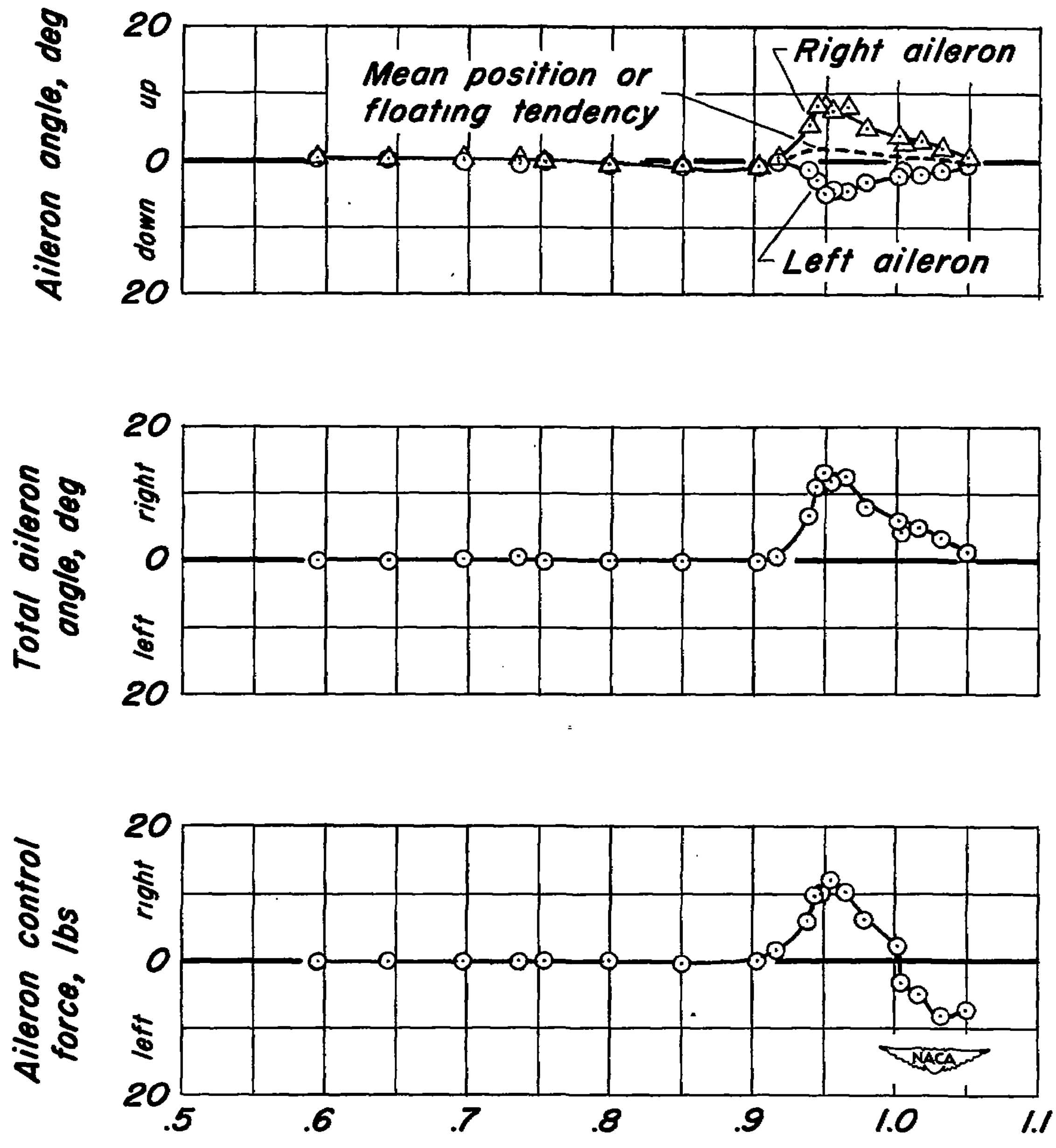

Figure 3.– The effect of Mach number on the aileron position and control force required to maintain wings-level flight on the test airplane at 35,000 feet.

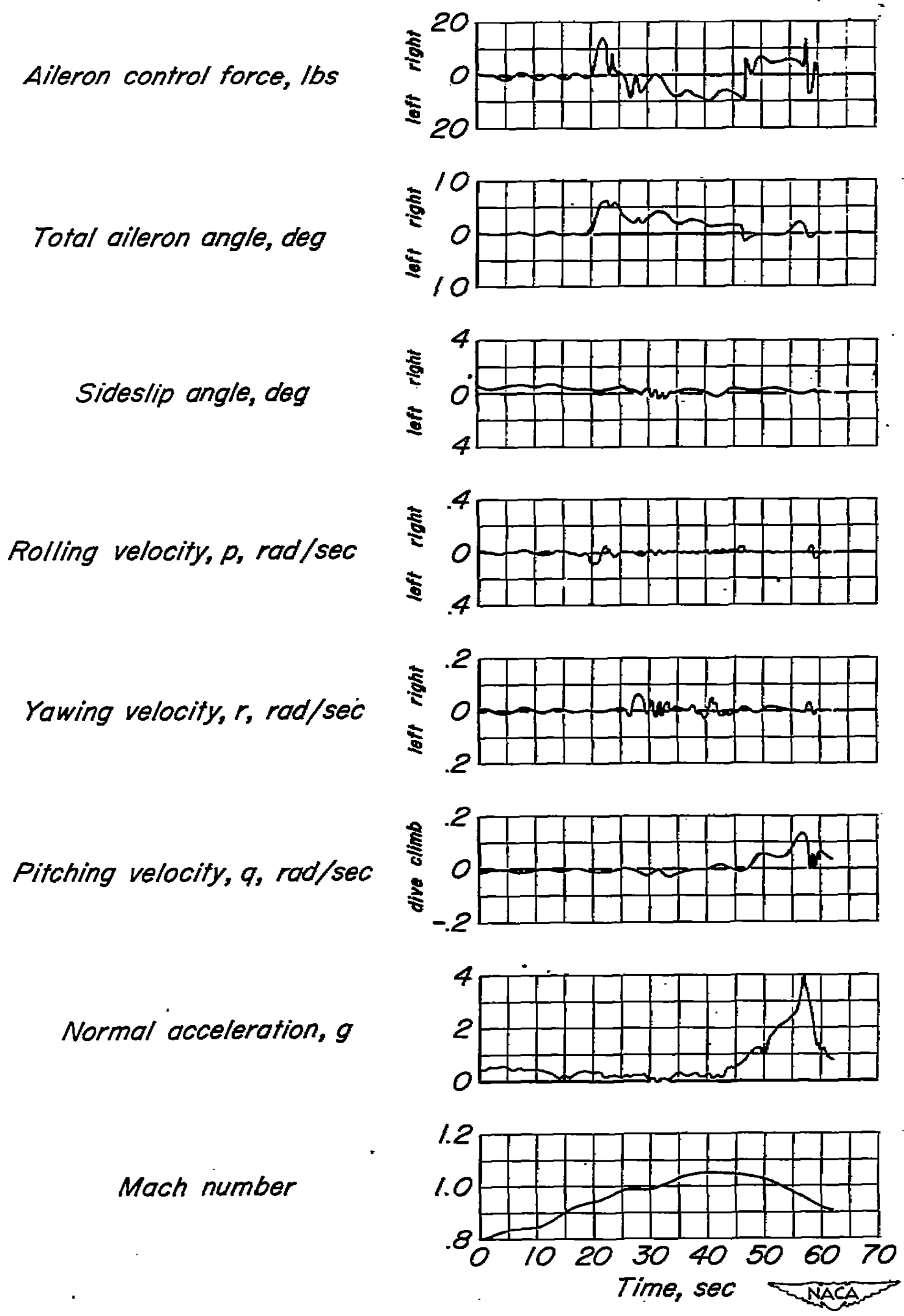

Figure 4.- Typical time history of a nominally wings-level dive from 0.80 to 1.05 Mach number at an average altitude of 35,000 feet.

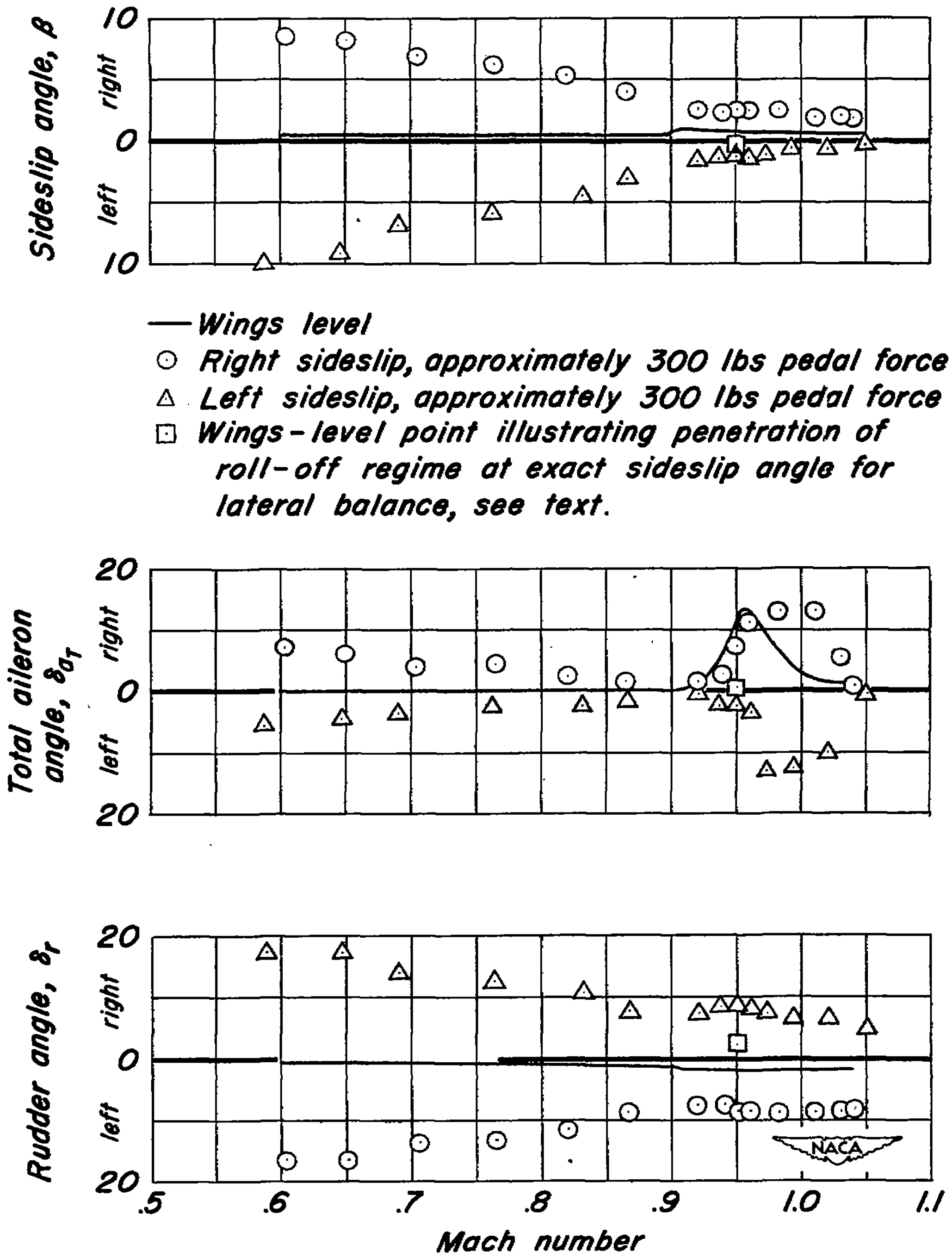

Figure 5.– The variation of the lateral trim characteristics with Mach number in left and right sideslips as well as the wings-level condition.

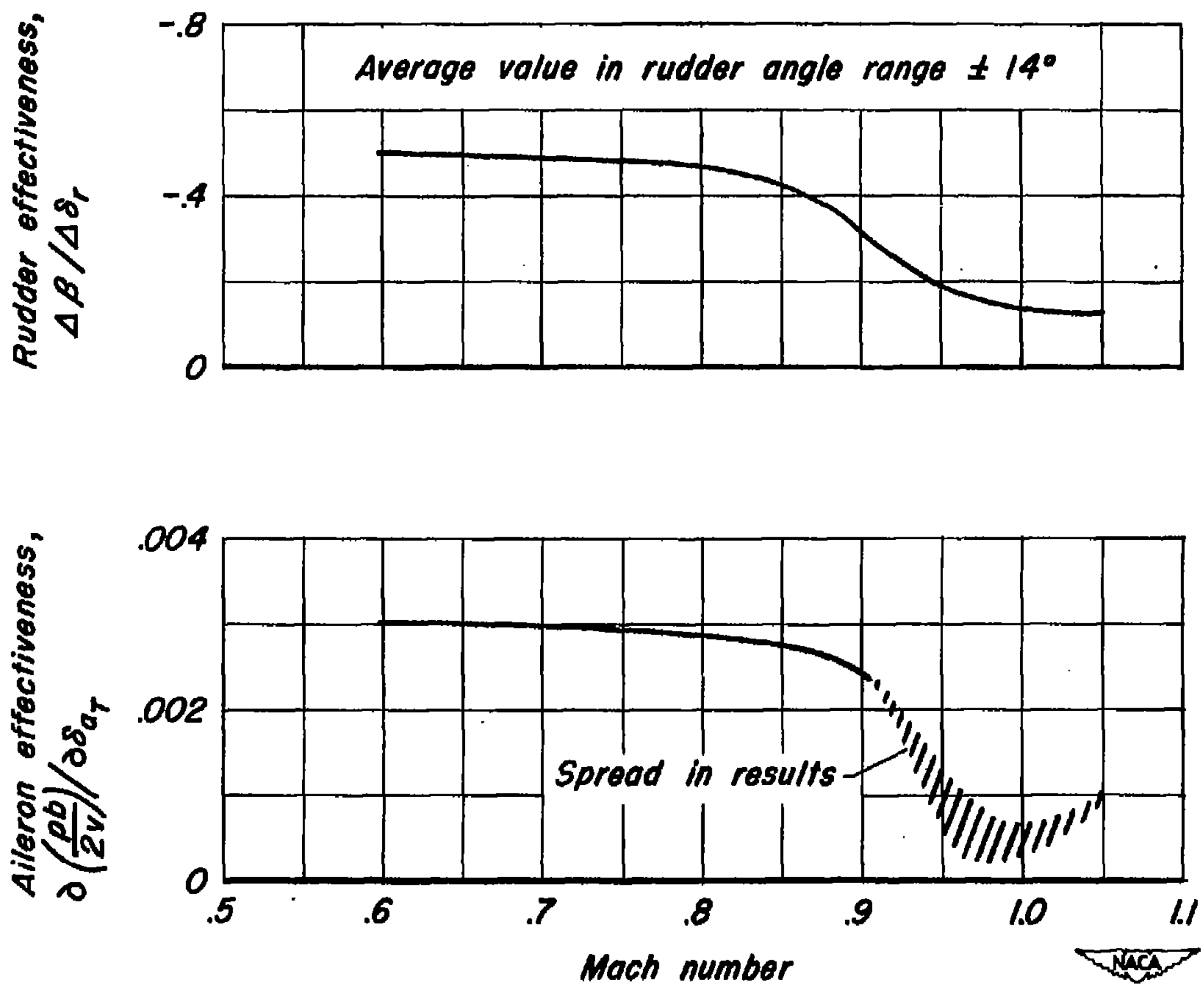

Figure 6.- The variation of aileron and rudder-control effectiveness with Mach number.

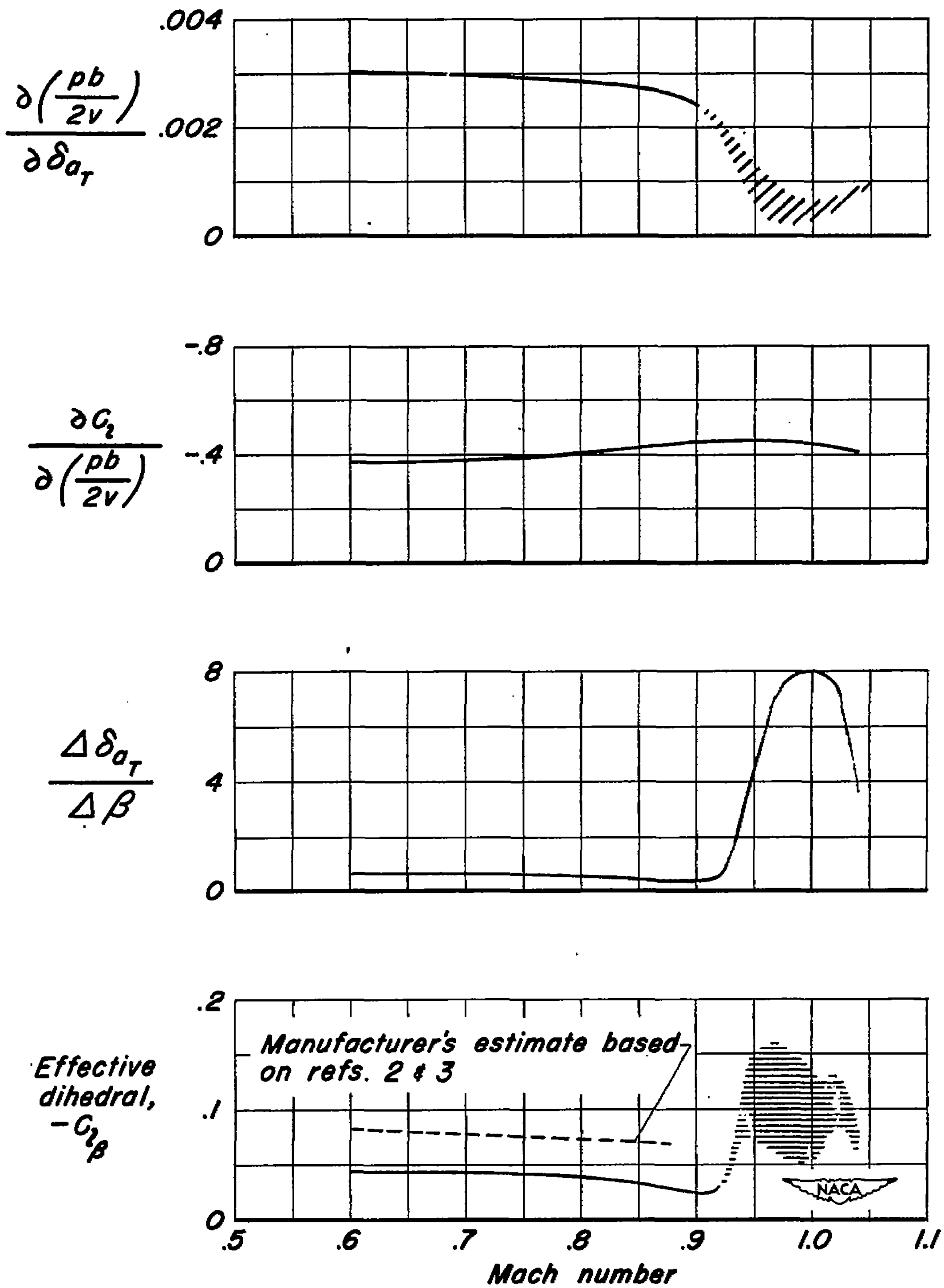

Figure 7.– Derivation of the approximate variation of effective dihedral with Mach number at level-flight lift coefficients, 0.37 to 0.11.

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